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RESEARCH AND DEVELOPMENT TECHNICAL REPORT

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MILLIMETER-WAVE SELF-MIXING InP and GaAs GUNN OSCILLATORS

Samuel Dixon

ELECTRONICS TECHNOLOGY & DEVICES LABORATORY

June 1979

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Self-oscillating mixers in both dielectric and waveguide cavities have been investigated in the 60 GHz frequency range. The devices consist of negative resistance diodes of GaAs and InP material coupled to waveguide cavities or high resistivity dielectric cavities such as silicon or Al_2O_3. Experimental measurements show that these devices have a sensitivity in the order of -80dBm with the intermediate frequency at 60 MHz and an IF bandwidth of 120 MHz. Applications are suggested based on minimum detectable signal and RF power capabilities for systems requiring small size and low cost.

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CONTENTS

INTRODUCTION

The self-mixing Gunn oscillator has been of considerable interest in recent years[1,2,3] because of the fact that this device embodies simplifications for the circuitry of electronic receiving systems. Schottky barrier and other rectifier diodes suffer from the disadvantage of fragility and low burn-out power levels. Bulk effect self-oscillating mixers using the nonlinearity of transferred electron (Gunn) devices offer competitive sensitivities and the attractive alternative of a high power handling capability. In conventional mixers, there usually exist a signal frequency, a mixer diode of the rectifier type, and a separate local oscillator. In the self-oscillating mixer, the mixer diode is eliminated. The Gunn diode will serve both as a local oscillator, and because nonlinearities are always present in an oscillator, as a mixing element. With the Gunn diode oscillator serving both these functions, a receiver front-end becomes extremely simplified and compact, especially when the dielectric image line approach is used. In the latter arrangement, the signal is fed directly into the oscillator and a suitable IF (intermediate frequency) probe will remove the IF power for use in subsequent amplifier stages. What makes self-mixing oscillators different intrinsically from the conventional mixing process with passive devices such as the Schottky junction diode is that self-mixing can occur with conversion gain (rather than loss) similar to parametric amplification[4].

One of the objectives of this report was the design of self-mixing oscillators with considerable simplication and hence reduction in cost. In the quest for lower cost, the image line technology was applied using a Gunn diode in a simply constructed cavity, in a self-excited oscillator-mixer mode of operation. Both GaAs and InP Gunn diodes were imbedded in an aperture which was cut in high resistivity Al_2O_3 ceramic waveguide. Metal waveguide cavity self-mixing oscillators were also evaluated for comparison. The significance of the dielectric waveguide technology is that active devices, as well as passive components, can be developed in-situ in circuit modules to construct functional integrated sub-systems.

DEVICE DESIGN

The metal waveguide self-mixing oscillators utilized a coax-waveguide hybrid circuit as shown in Fig. 1. The packaged diode is imbedded in a copper heat sink at the end of a coaxial line section. A large portion of the outer conductor is removed with the removed section facing the waveguide opening to form a broadband coaxial-to-waveguide transition. A wide-band choke is used to terminate the opposite end of the line. The dc bias to the Gunn diode and extraction of the IF power is also provided at this end.

The dielectric image line oscillator cavity design is based on an image line concept first formulated by Marcatili[5] and later modified for millimeter waves [6,7]. The fundamental electromagnetic wave propagating in an

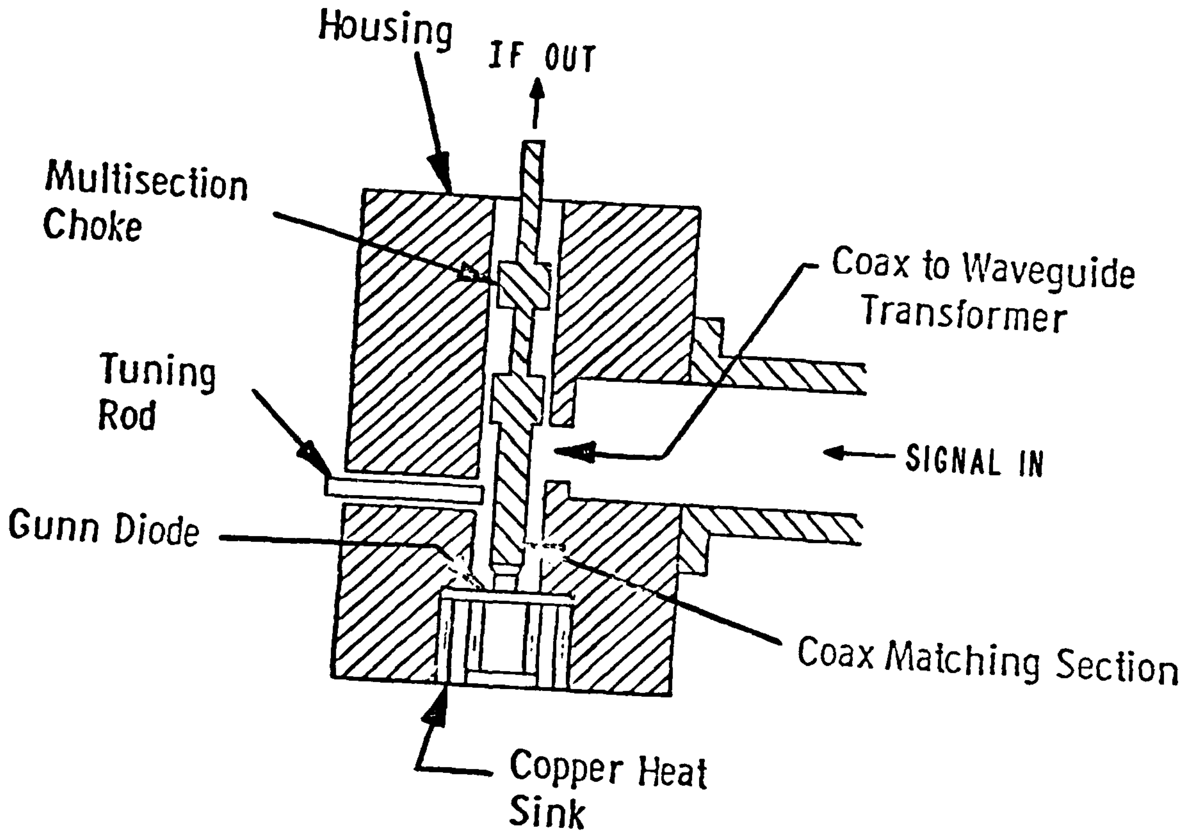

Figure 1. Cutaway view of waveguide self-oscillating mixer

image line is the E^Y_{11} mode, a hybrid mode which propagates when correctly launched. Application of theoretical considerations indicated that the image guide, which exhibits low propagation loss at millimeter-wave frequencies, for proper operation should be on the order of one wavelength in the medium in width, and less than one-half wavelength in height. The cross-sectional dimensions of alumina at 60 GHz which has a dielectric constant of approximately 9.0, were slightly greater than 1 millimeter in height and about 2 millimeters in width. Experiments indicated that in this oversized condition, the E^Y_{11} mode dominated. The resonant length of the dielectric section in back of the diode was chosen for optimum power. This was approximated to be $(2n+1)\ \lambda/2$ in length.

A simplified schematic of the self-mixing oscillator is shown in Fig. 2. This indicates the manner of coupling to the metal waveguide showing one end of the resonant cavity being tapered. The dielectric image guide taper can effect a low loss waveguide to image guide transition by simply inserting into the full height waveguide opening and adjusting the protrusion for maximum power transfer. This matched condition also yielded optimum IF output when an RF input signal was introduced. Figure 3 gives a more detailed cutaway view of the image guide device investigated. As can be seen, the IF exits out of the top of the structure with a metal disc being utilized as a matching element from Gunn diode to image guide. Figure 4 shows an exploded view of the self-mixing oscillator which utilized a tuneable short as an impedance matching device and Fig. 5 shows the same unit ready for operation. Referring to Fig. 4, the metal diode housing was designed for minimum radiation leakage with dimensions that were oversized with respect to WR-15 waveguide. The Gunn diode is mounted flush with the bottom of the metal structure. The aluminum oxide (Al_2O_3) dielectric waveguide with tapered front end was bonded to the metal housing in such a way that the Gunn diode tip protruded up into the dielectric. A .045" hole in the dielectric waveguide allowed the IF and bias voltage post to make a pressure contact with the top of the Gunn diode. This made it possible to mount a sliding short behind the image guide for impedance matching and tuning.

EXPERIMENTAL RESULTS

Figure 6 shows the output power and frequency characteristics of an InP diode in a waveguide cavity as a function of the bias voltage. It should be noted that the frequency can be tuned over a range of 280 MHz with a change of bias of 1.2 volts. This change in bias voltage gave a change in output power from 19 to 23 mW. Similar characteristics were obtained with the GaAs Gunn diode in a waveguide cavity except that the peak bias voltage was in the order of 4.5 volts with peak powers of 6.5mW. These peak output powers are typical of those used in the self-mixing experiments. Figure 7 shows a block diagram of the RF circuit used in evaluating the two types of self-mixing Gunn oscillators. A backward wave oscillator in a mechanically tuneable mode was used as the signal source. The single frequency outputs from this source were stablewithin $\pm$.001% with non-harmonic spurious signals that are 40dB

DIELECTRIC SELF-OSCILLATING MIXER COUPLING TO WAVEGUIDE

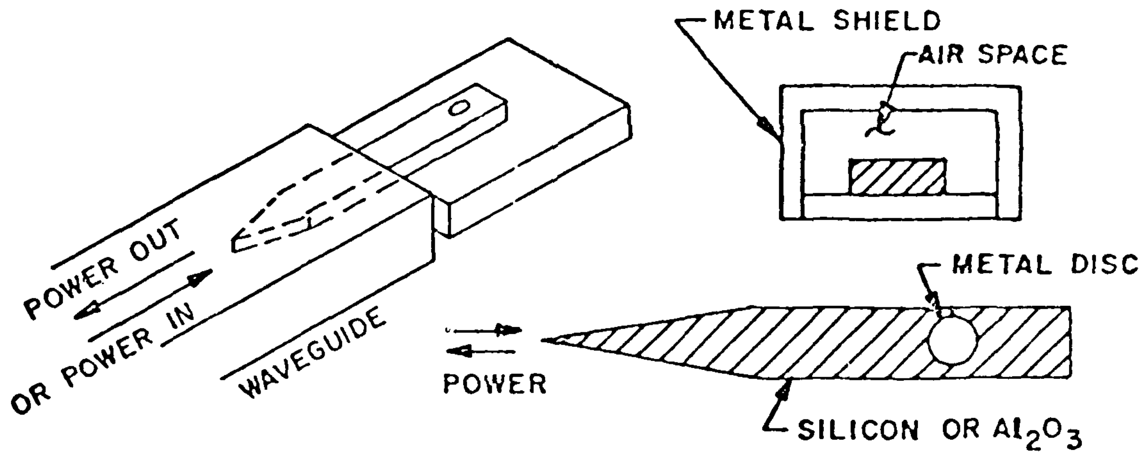

Figure 2. Image-Guide self-oscillating mixer coupling to waveguide

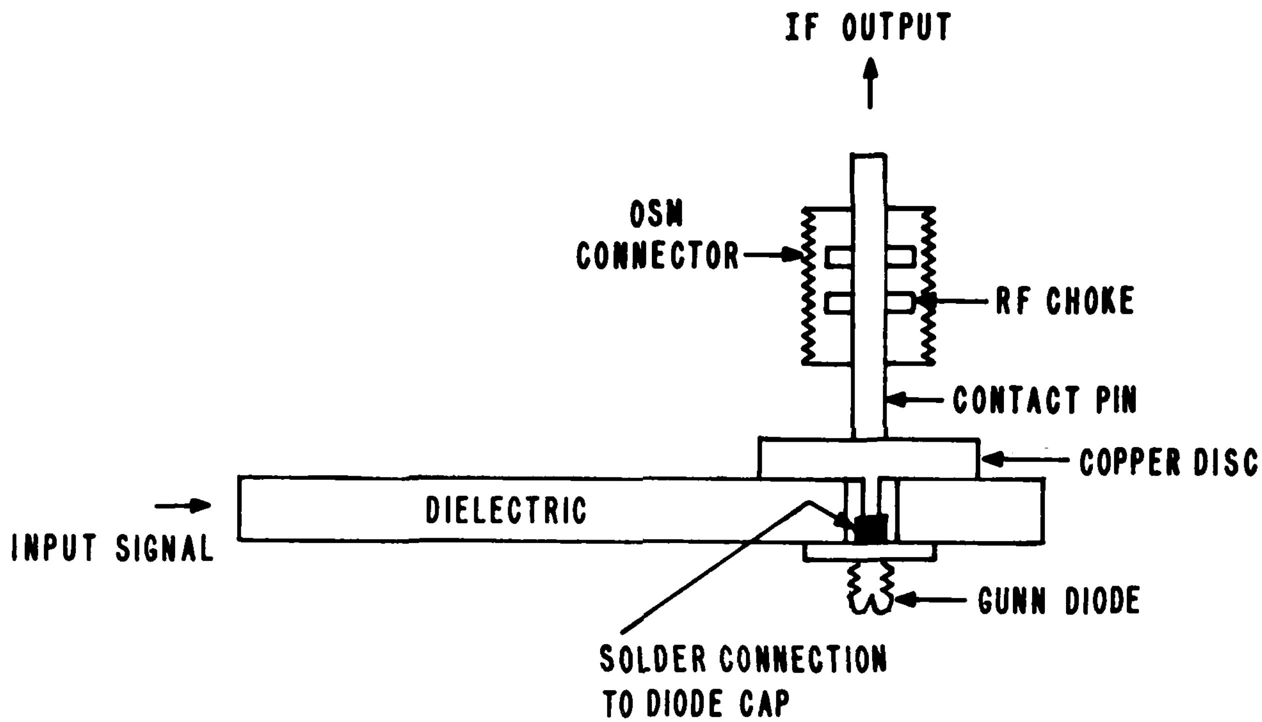

Figure 3. Cutaway view of dielectric waveguide self-oscillating mixer

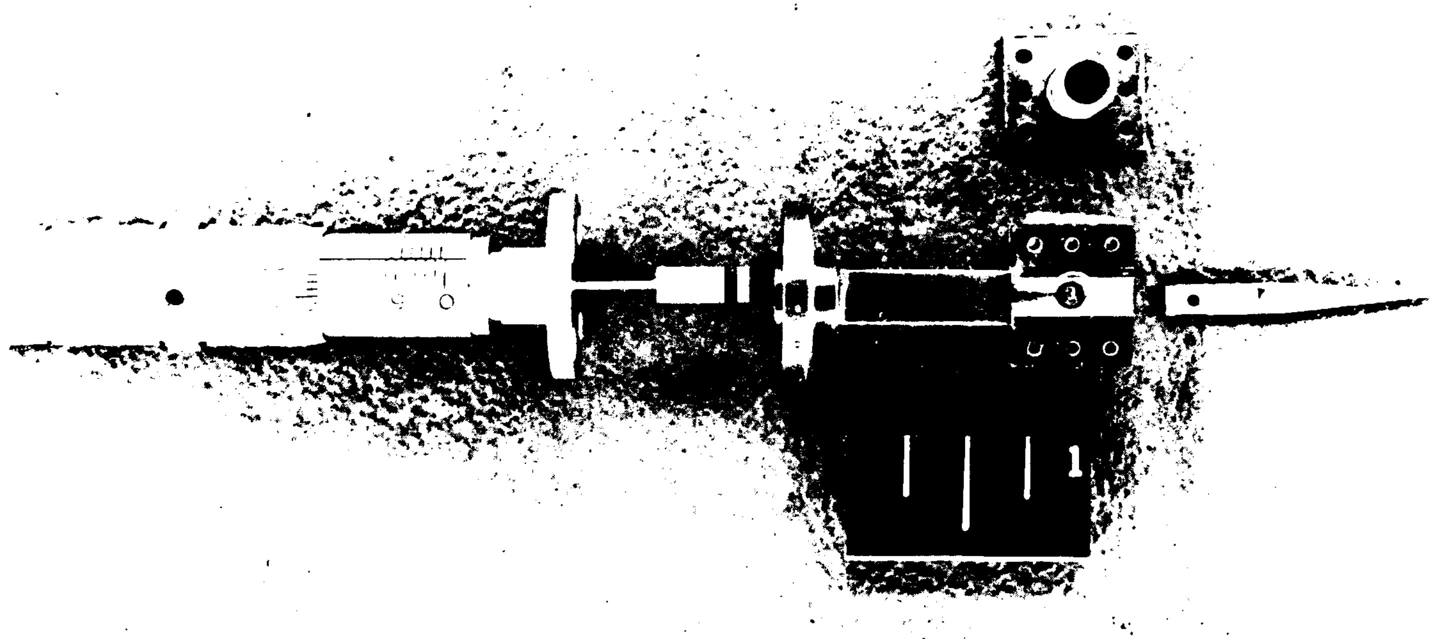

Figure 4. Exploded view of dielectric image guide self-oscillating mixer

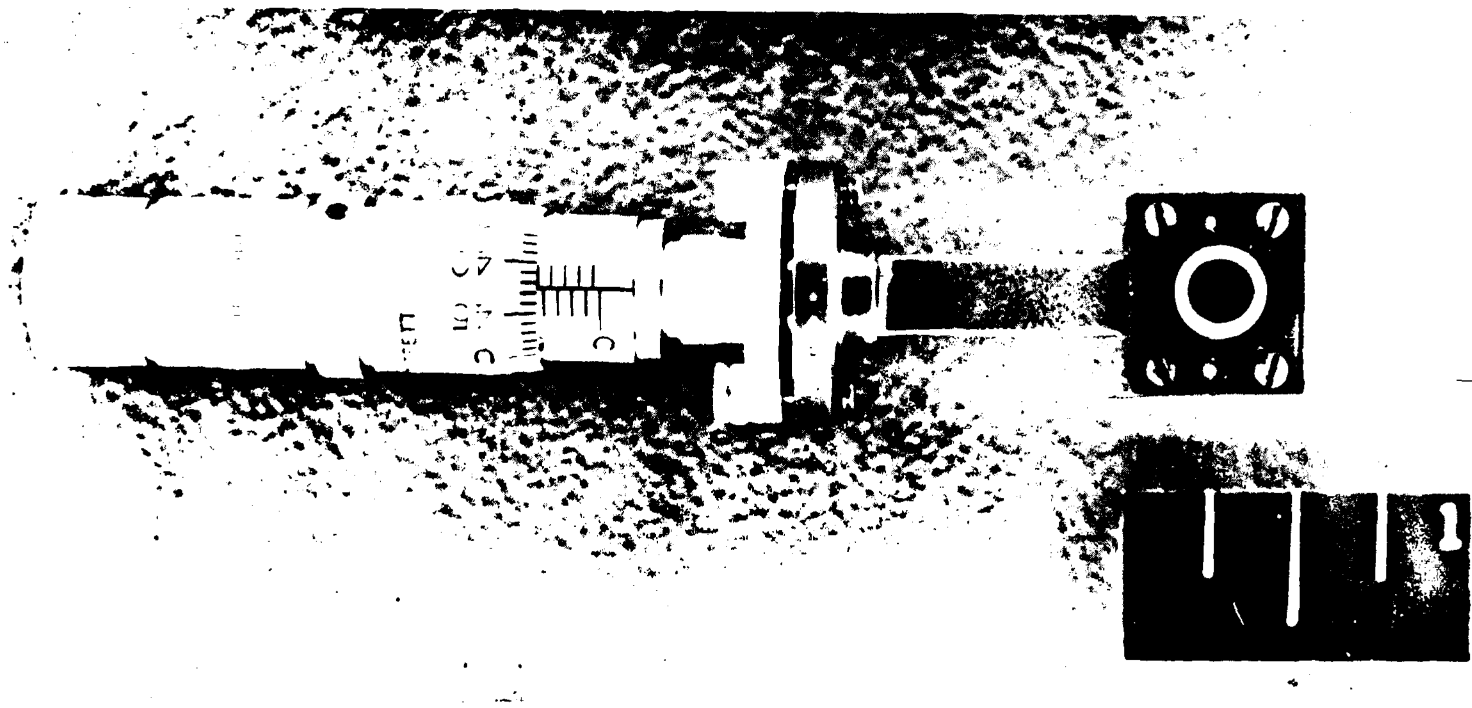

Figure 5. Assembled Dielectric Waveguide Self-Oscillating Mixer

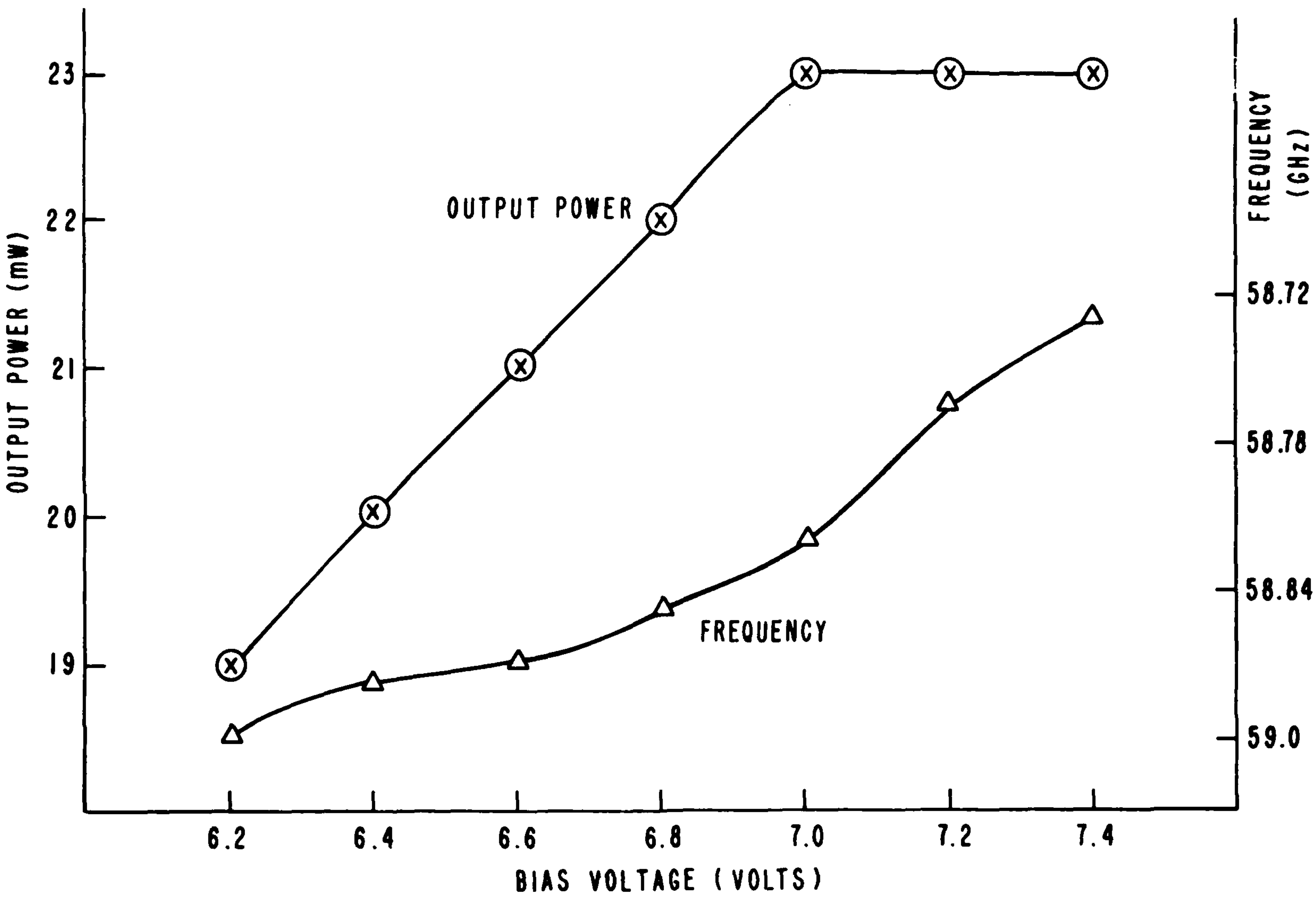

Figure 6. Characteristics of InP waveguide cavity oscillator

BLOCK DIAGRAM OF MILLIMETER-WAVE SYSTEM USED IN MEASUREMENTS OF MINIMUM DETECTABLE SIGNAL

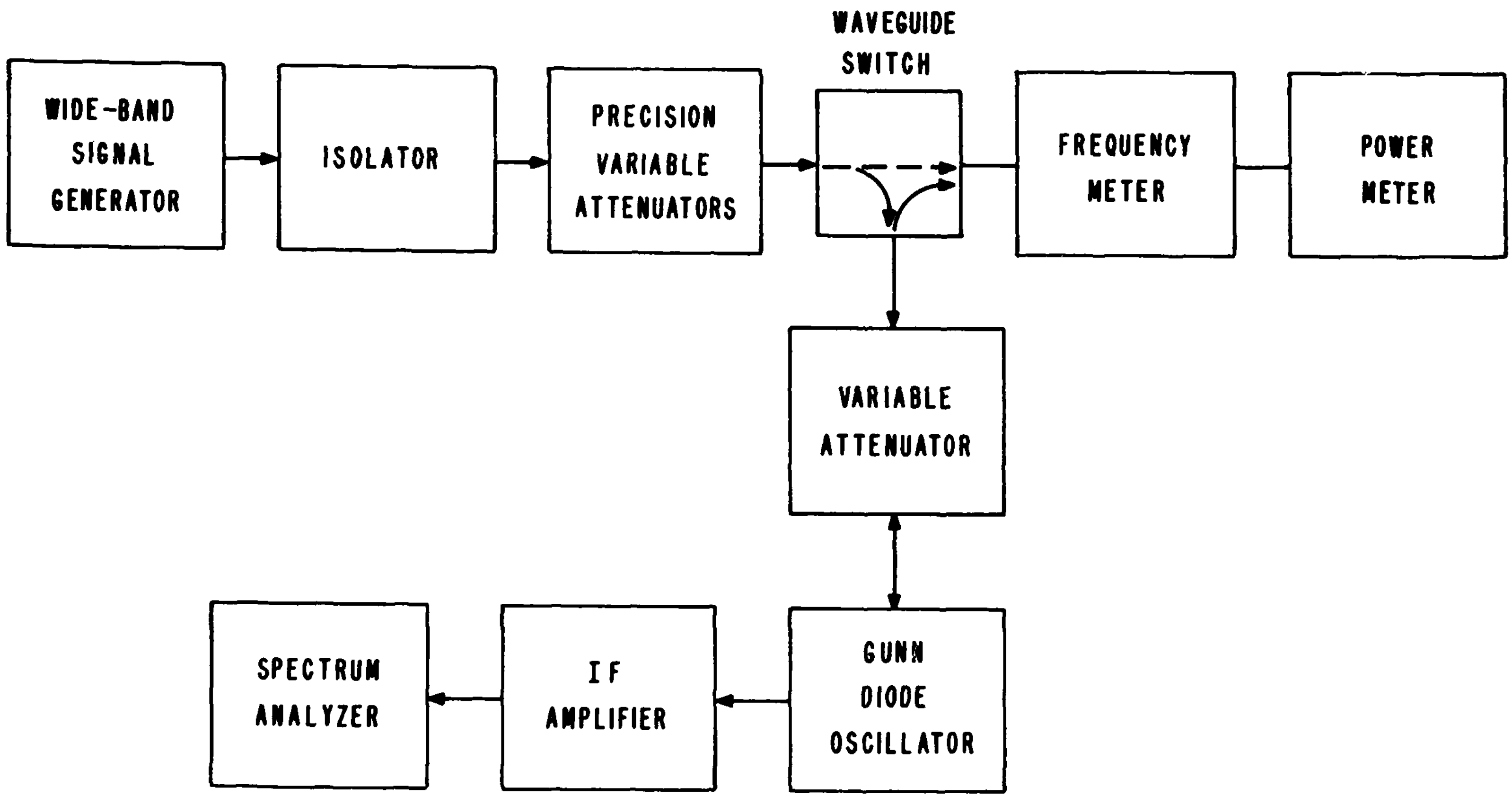

Figure 7. Block diagram of measurements system for minimum detectable signal

down. This highly stable signal was tuned 60 MHz above or below the Gunn oscillator frequency to produce an IF frequency. The difference signal at 60 MHz was displayed on the face of the spectrum analyzer oscilloscope. By increasing attenuation in the signal channel, the IF energy pulse could be made to decrease and disappear into the noise level of the spectrum analyzer. The attenuation was then decreased until the detected IF power is 3dB above the noise level. At this point the signal level is equal to the noise level and this IF power is defined as the minimum detectable signal power measured in decibels referred to 1mW. The oscillating diode was tuned by the bias voltage above the threshold field and also by the RF circuit to achieve the desired operating point. Care was taken to insure that no spurious oscillations or bias circuit instabilities were present. The amplitude of the IF power in dBm was compared with measured values of input signal power for conversion gain or loss measurements. Figure 8 shows the IF output power as a function of signal power input for a GaAs Gunn diode in a waveguide cavity. Figure 9 shows the same variables utilizing a metal waveguide cavity for an InP Gunn diode. The data point at the lowest signal power indicates the point where the IF output power disappears into the noise level of the spectrum analyzer. As can be seen, the GaAs and InP Gunn diodes have a minimum detectable signal (MDS) in the order of -77 and -81 dBm, respectively. This minimum detectable power is the principal parameter for determining the sensitivity of a self-mixing oscillator, that is, how weak a signal the device can detect. Figure 10 shows the conversion gain measured on the GaAs self-mixing oscillator. Figure 11 shows the same information for the InP device. As can be seen, the gain is in the order of 12dB for the InP oscillator while for GaAs it is 9dB. The data also indicates that the conversion gain increases as the signal power decreases.

In the quest for a much lower cost device, GaAs and InP Gunn diodes were imbedded in an image guide cavity structure and their performance evaluated. Figure 12 shows the output power and frequency characteristics of a GaAs diode, imbedded in image guide, as a function of the bias voltage. Figure 13 shows the same variables with respect to an InP diode. The data indicate a frequency-bias tuning range of 120 MHz for the GaAs device and 220 MHz for the InP self-mixing oscillator. However, the frequency tuning rate is much steeper for the InP diode as a function of the bias voltage, which is very advantageous for certain system applications. Figures 14 and 15 show the IF output power as a function of signal power input for both the GaAs and InP self-mixing oscillators respectively. The sensitivities of the image guide devices are in the same order of magnitude as that of their waveguide counterparts. Figures 16 & 17 show the conversion gain measured with image guide self-mixing oscillators, which was again comparable to that measured with waveguide devices.

DISCUSSION OF RESULTS

In terms of sensitivity the data indicates that the InP self-mixing oscillator's performance in both image guide and metal waveguide cavities is

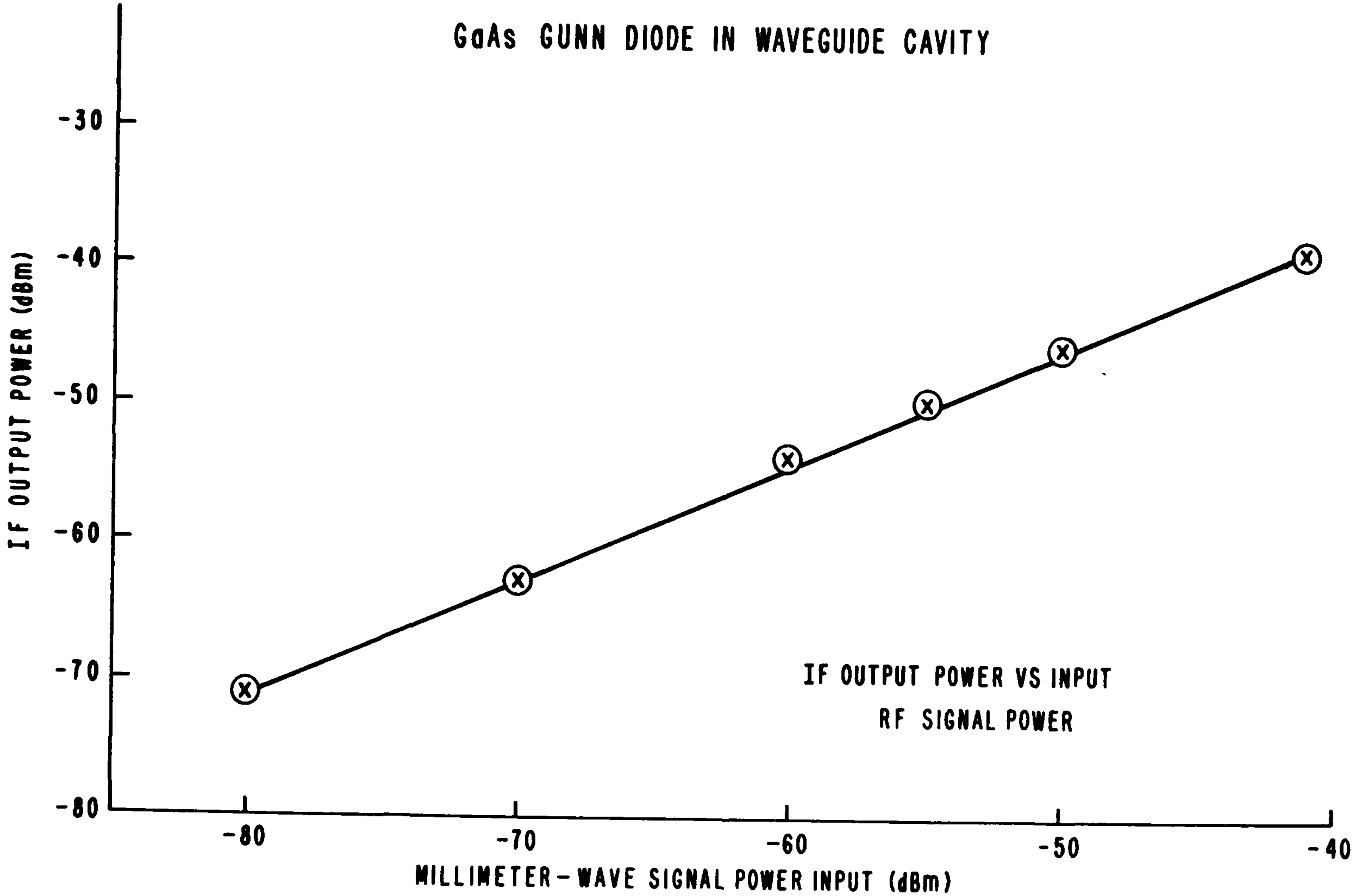

Figure 8. IF output versus signal power for GaAs Gunn Diode in waveguide cavity

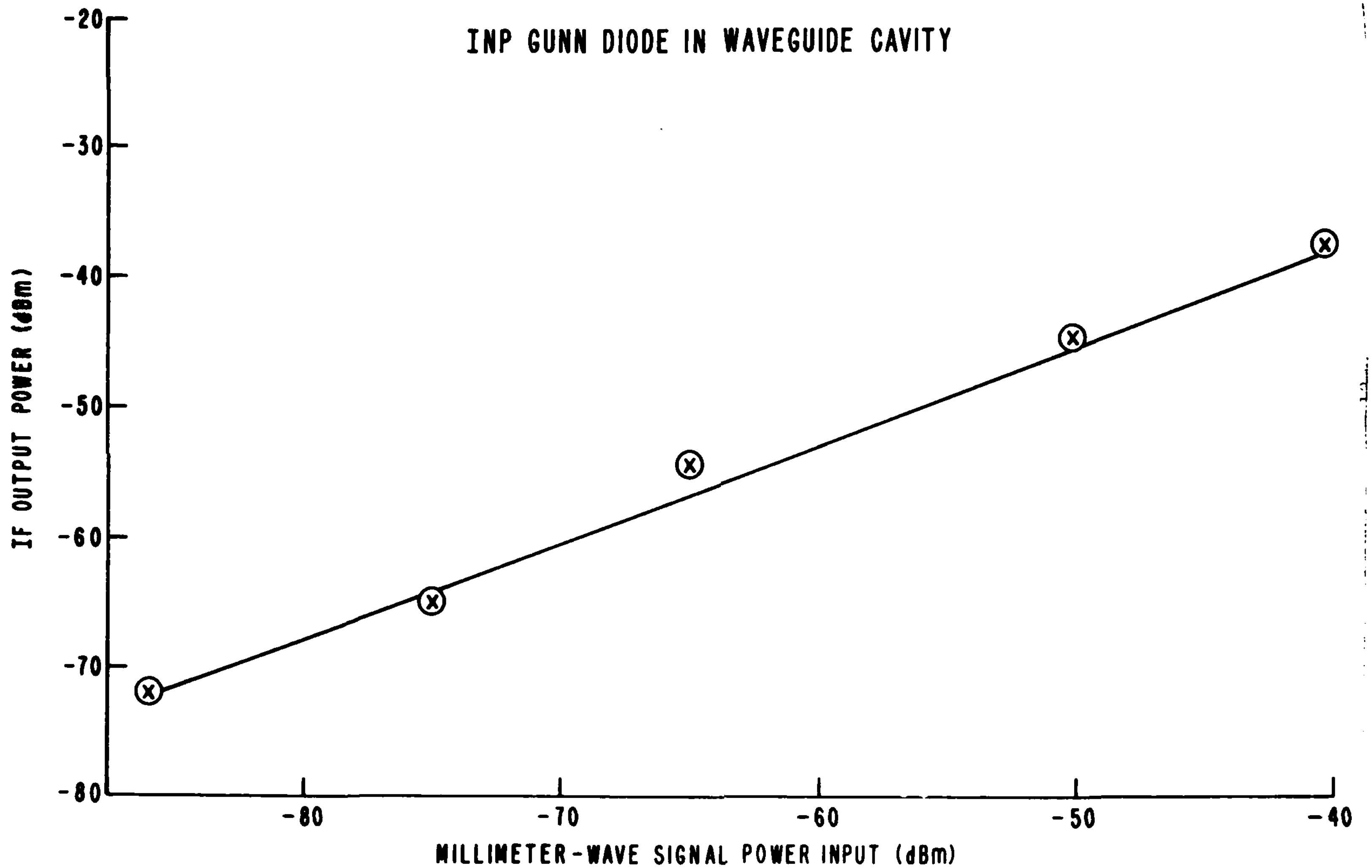

Figure 9. IF output versus signal power for InP Gunn Diode in waveguide cavity

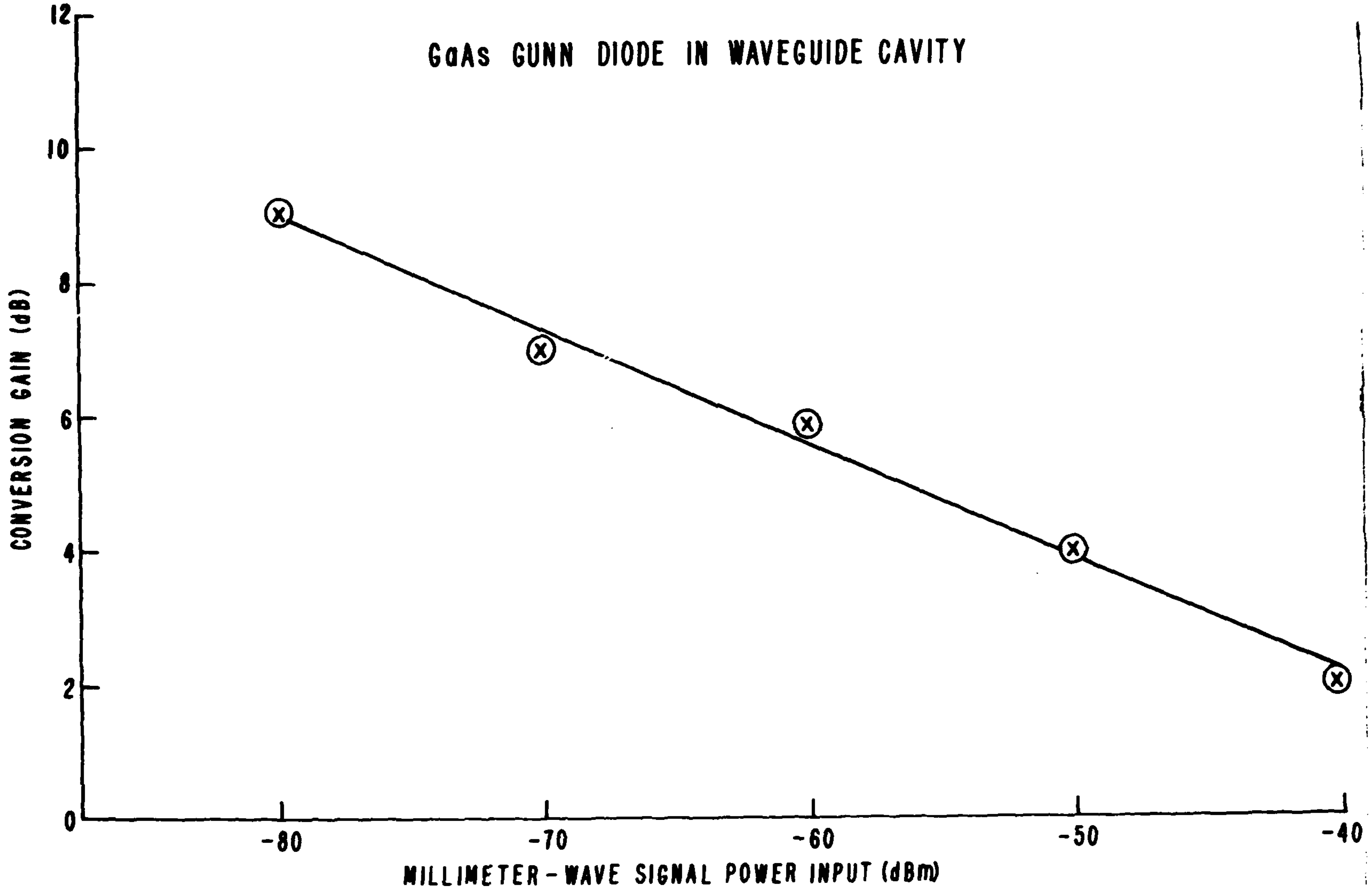

Figure 10. Conversion Gain versus signal power for a GaAs Gunn Diode in waveguide cavity

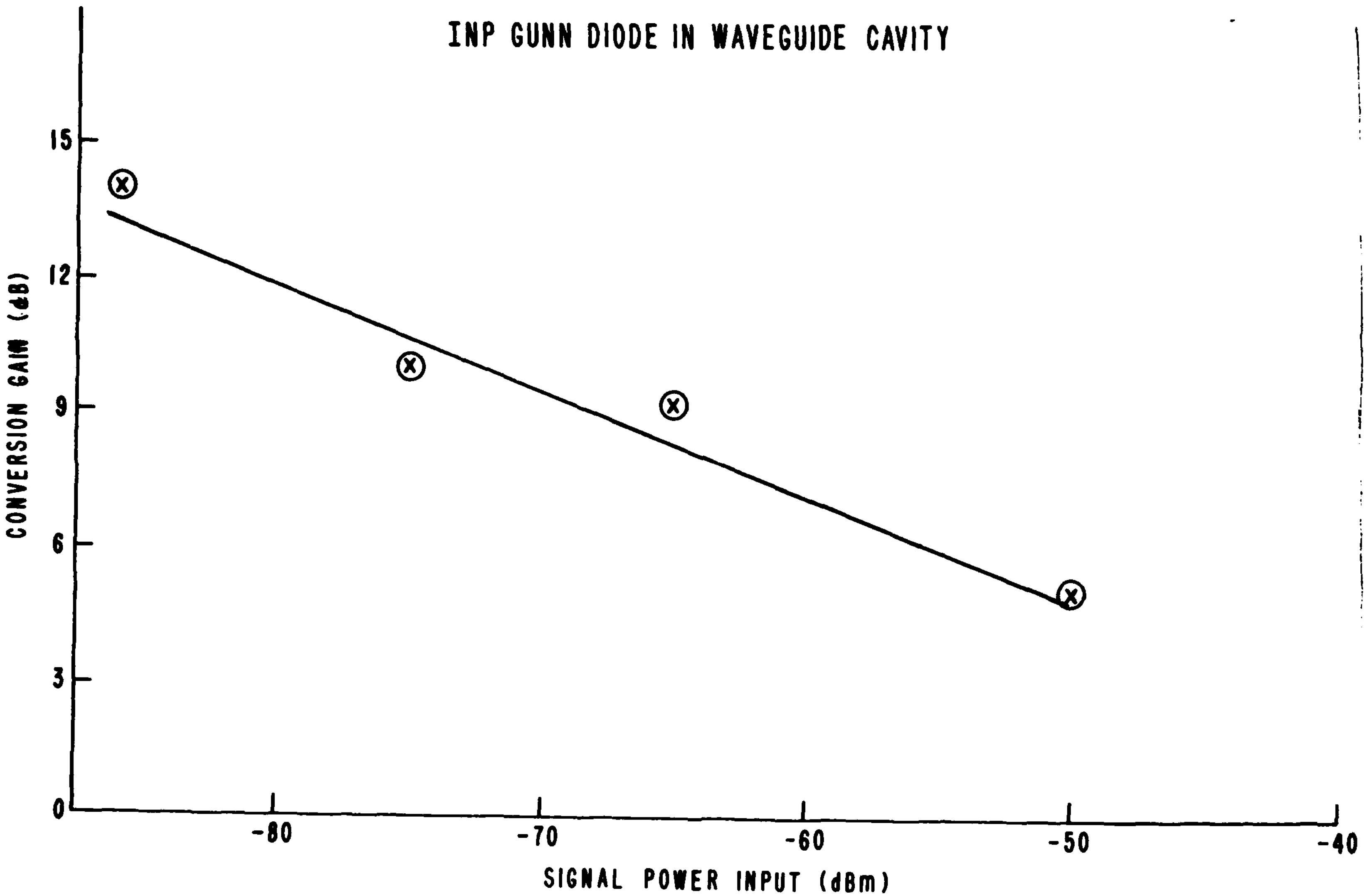

Figure 11. Conversion Gain versus signal power for InP Gunn Diode in waveguide cavity

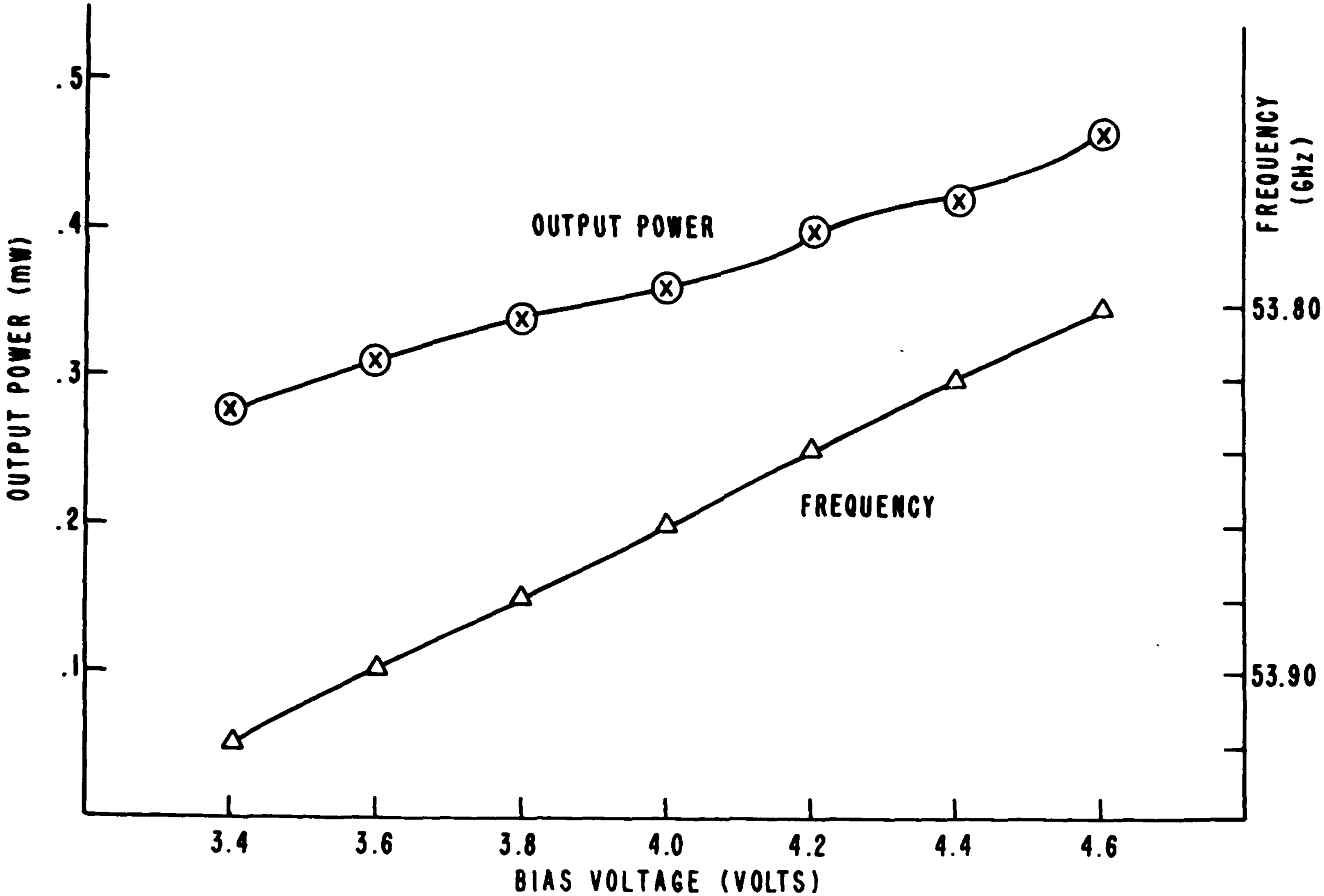

Figure 12. Characteristics of GaAs dielectric waveguide oscillator

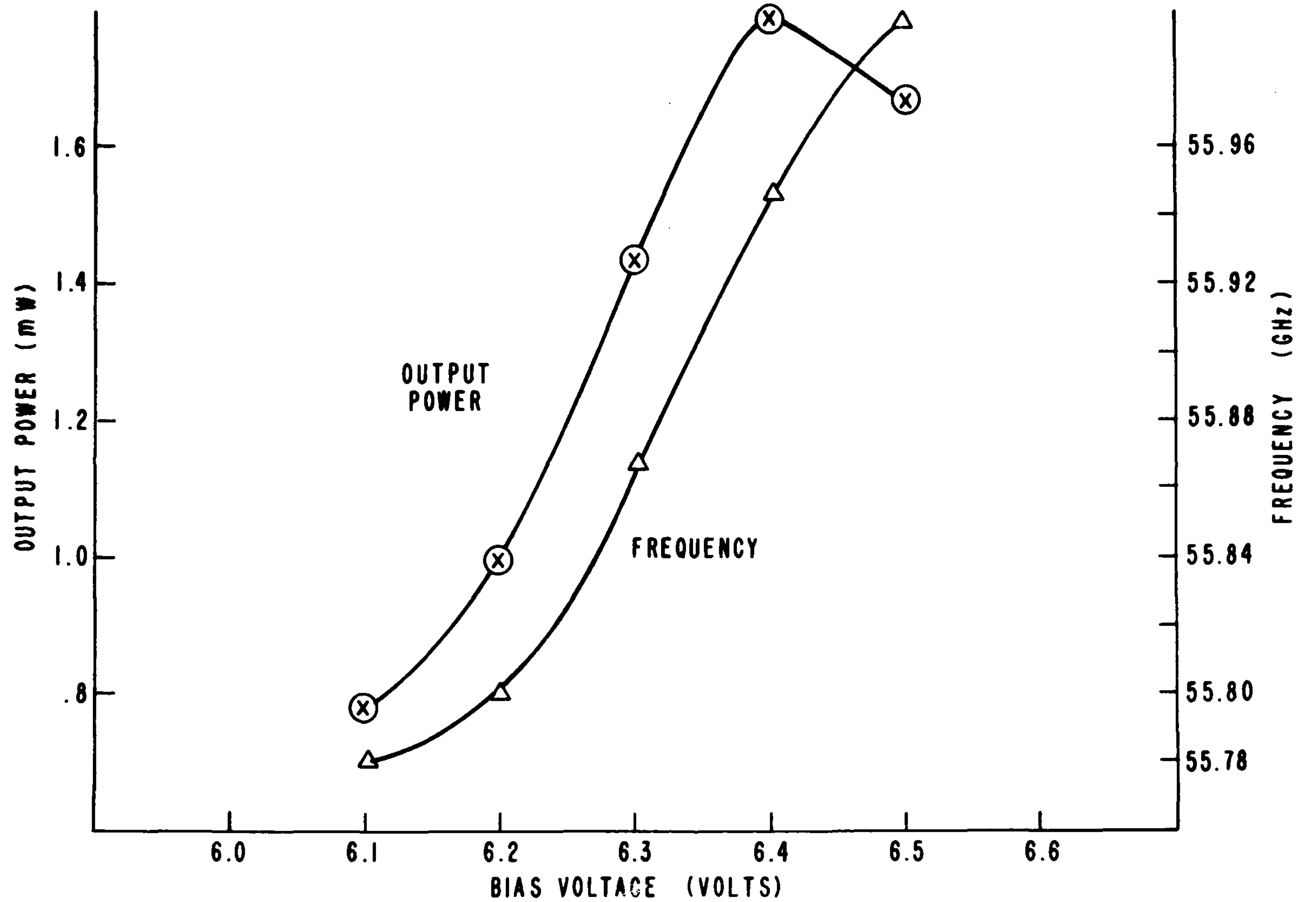

Figure 13. Characteristics of InP dielectric waveguide oscillator

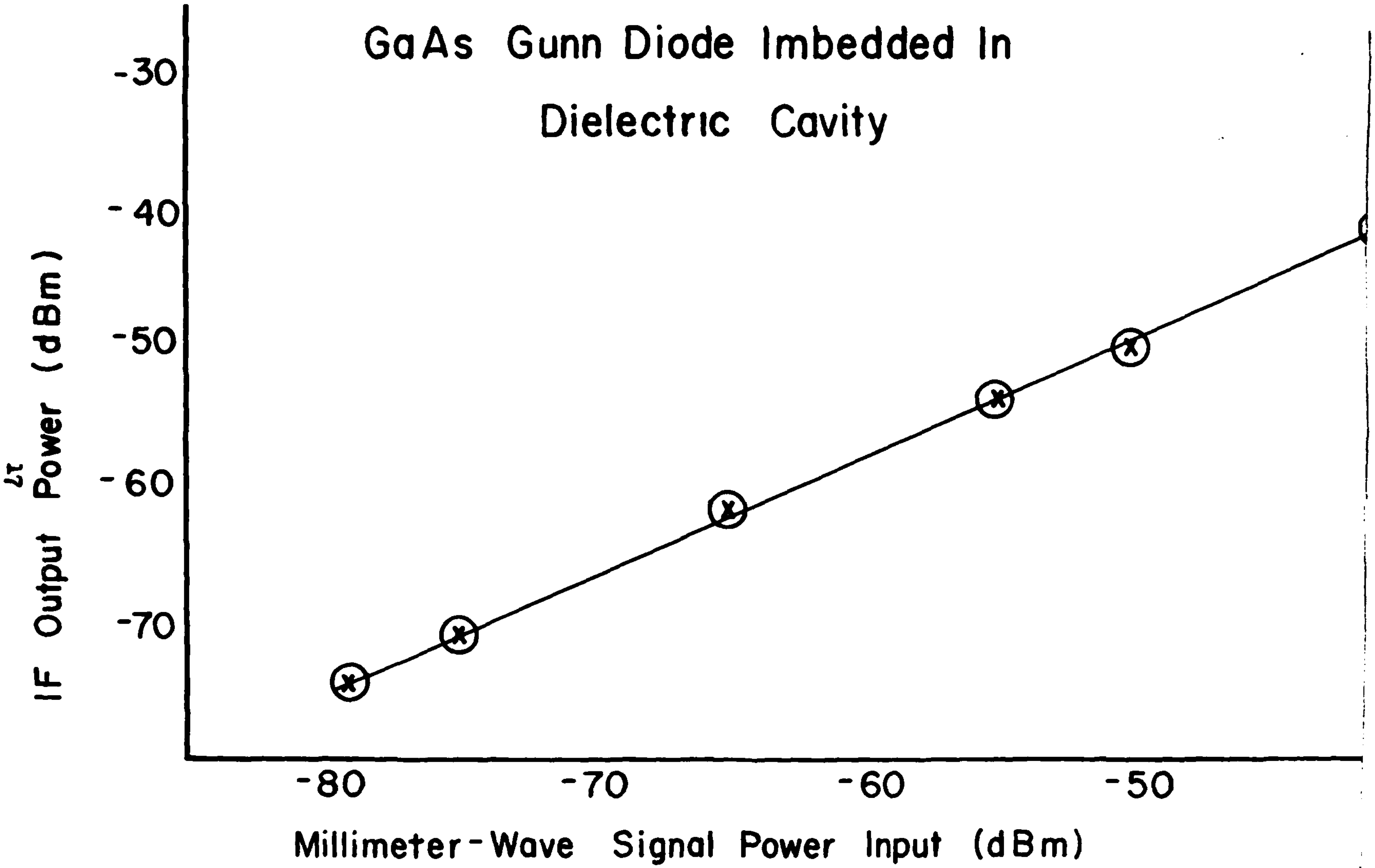

Figure 14. IF output versus signal power for GaAs Gunn Diode in dielectric waveguide

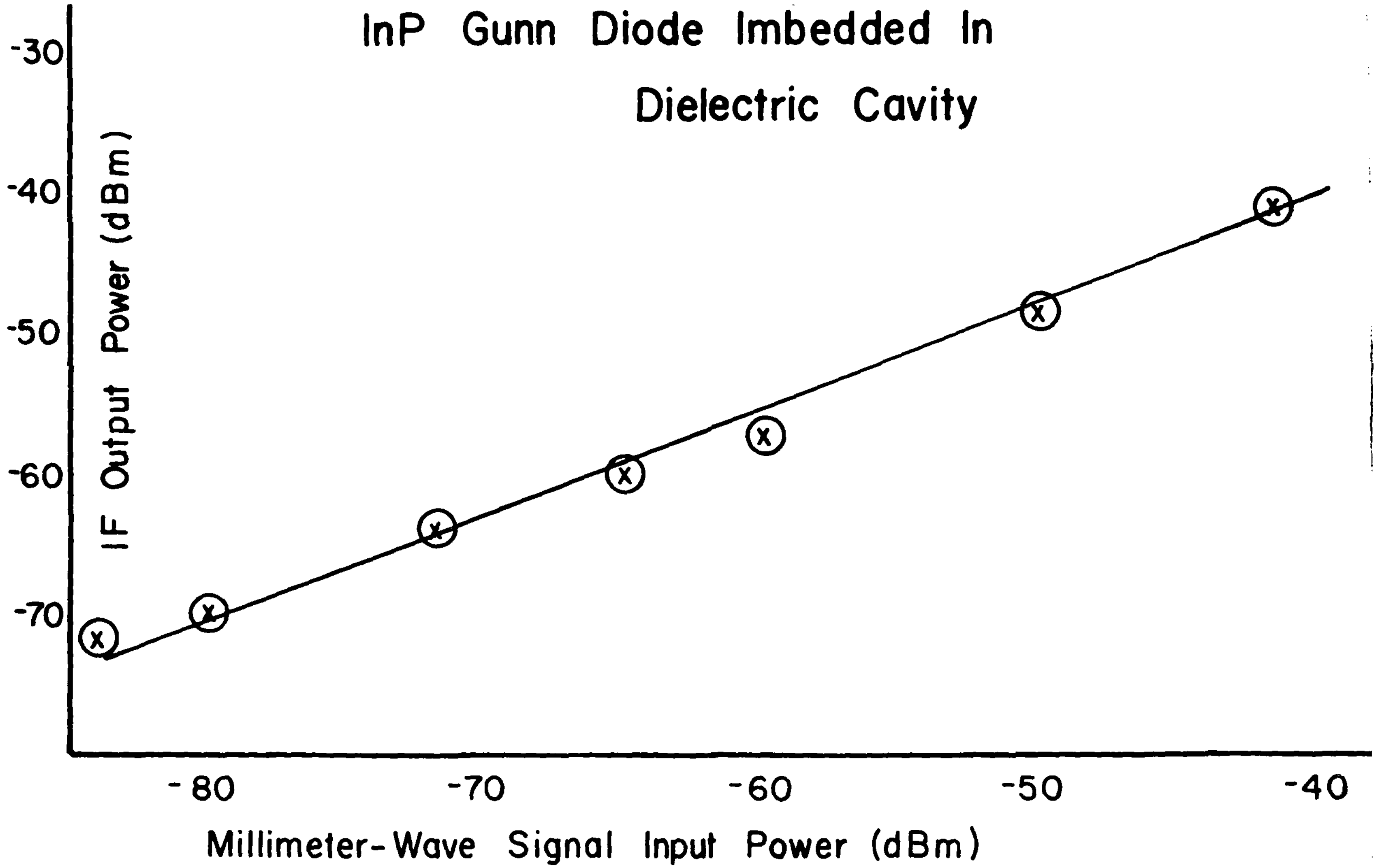

Figure 15. IF output versus signal power for InP Gunn Diode in dielectric waveguide

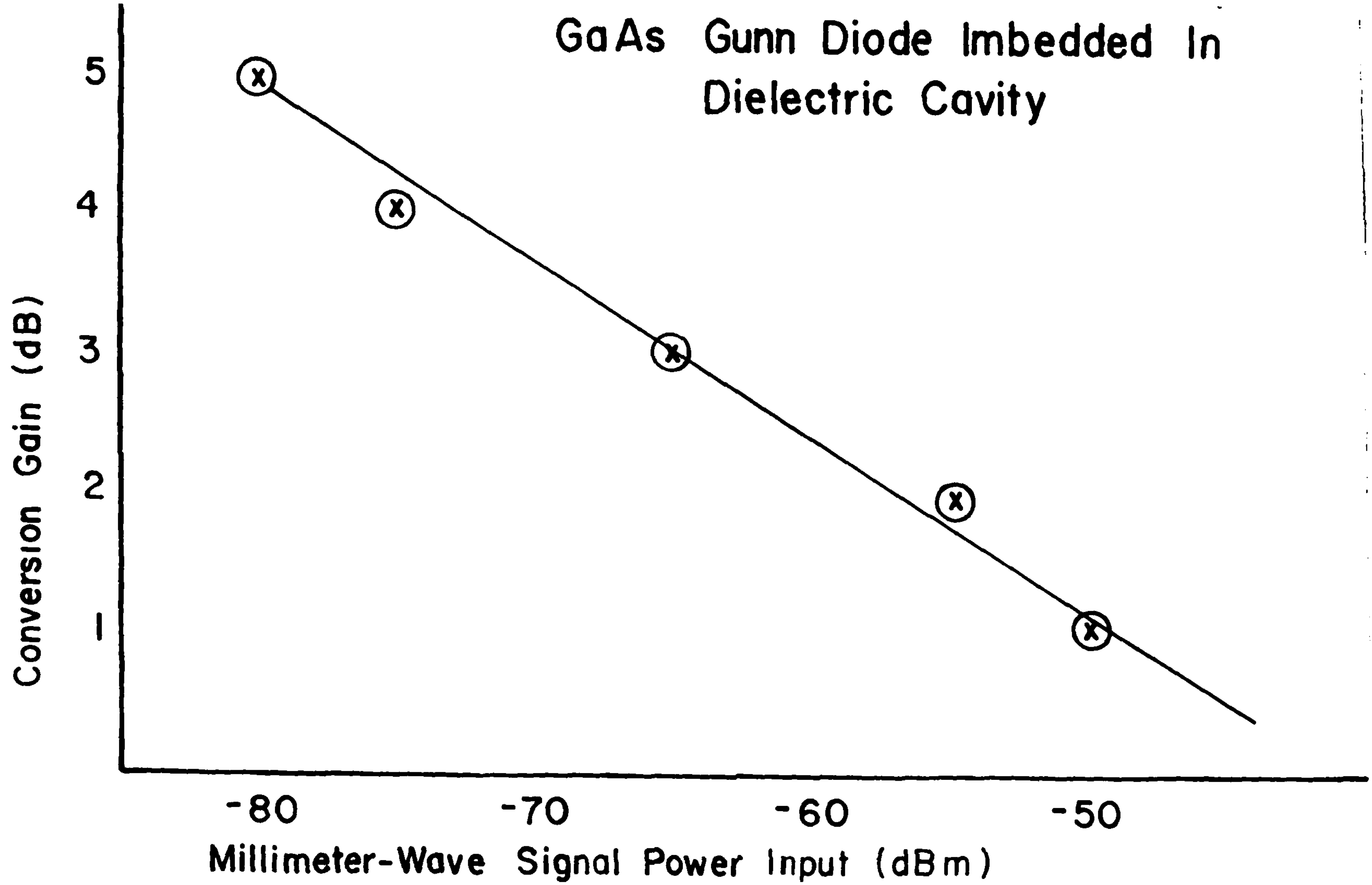

Figure 16. Conversion Gain versus signal power for a GaAs Gunn Diode in dielectric waveguide

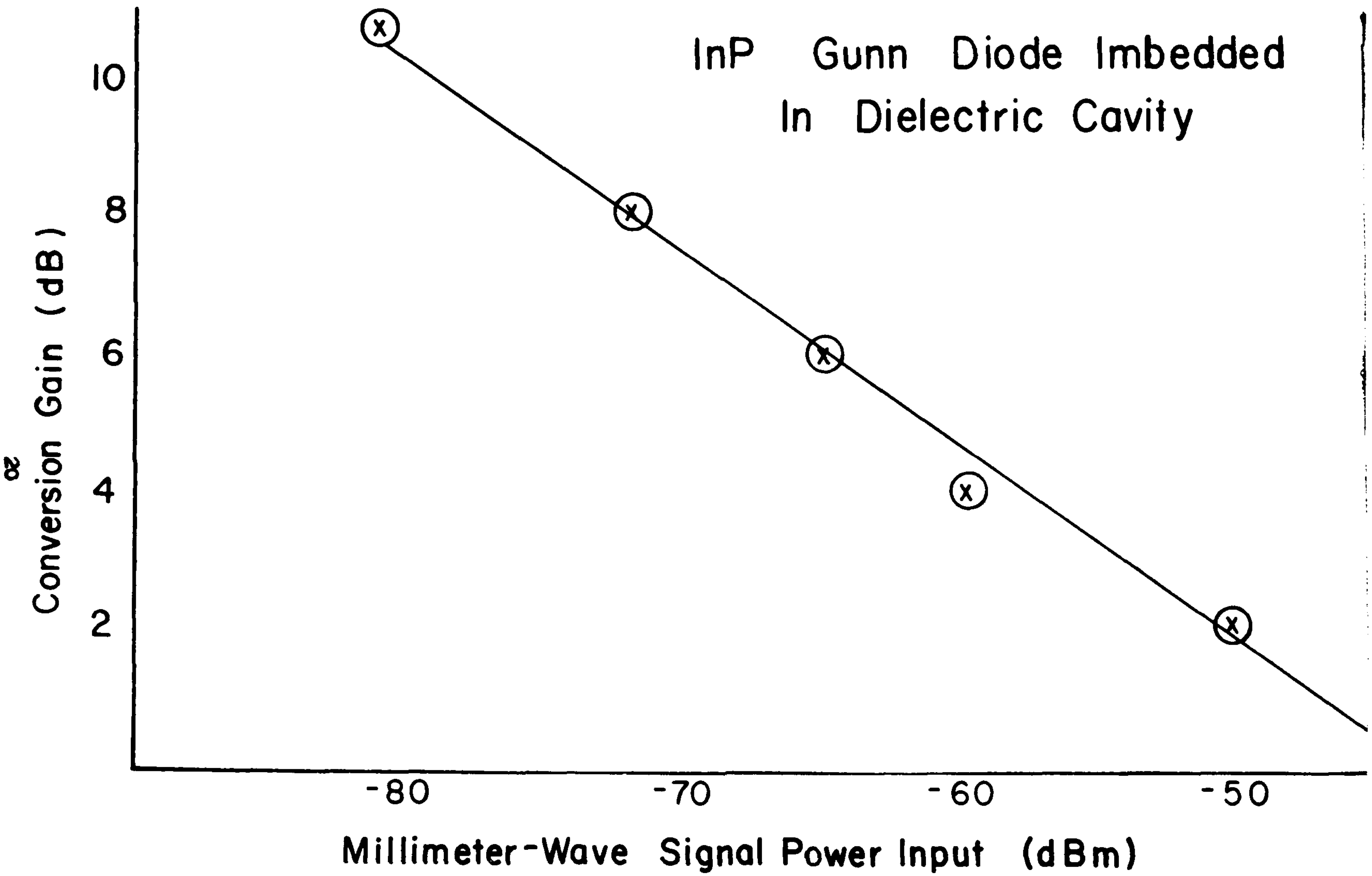

Figure 17. Conversion Gain versus signal power for InP Gunn Diode in dielectric waveguide

better than that of the GaAs device. The reasons for superior performance of the InP may lie in the following factors. It has a current peak-to-valley ratio of 3.5 as opposed to 2.5 for GaAs [8]. This, in theory, [9] will provide higher conversion efficiencies. In addition, the peak-to-valley ratio in InP degrades less rapidly with temperature changes than GaAs and the thermal conductivity is greater, thus favoring CW operation. An inherent characteristic indicated by the experimental data is that the sensitivity or conversion gain increases as the signal level decreases. This characteristic has been reported by other investigators for waveguide self-mixing oscillators at 34 GHz [1, 4].

The major objective for this program was to design a low cost device, with simple construction and lightweight for application in integrated circuit modules and sub-assemblies. The dielectric image line approach seems well suited to accomplishing these objectives. The sensitivities of -77dBm for GaAs and -81dBm for InP self-mixing oscillators obtained in this development make them attractive for application in mixer devices for certain applications.

CONCLUSIONS

It has been shown that GaAs and InP diodes imbedded in dielectric waveguide cavities in a simplified design circuit will give comparable sensitivities to that of metal waveguide cavity self-mixing oscillators. Experimental data indicates that the sensitivity of these devices are in the order of -80dBm which made them competitive with other conventional mixers. However, the image guide device has the advantage of having simplified construction with a high signal power burnout level coupled with very low unit cost. These characteristics make the image guide self-mixing oscillator, a viable device in low cost receivers, expendable EW sensors, and short range terminal guidance. In addition, the InP self-mixing device has great potential in the higher millimeter-wave frequency region (above 100 GHz) due to its higher effective transit velocity and fast intervalley scattering.

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